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Network impacts of a road capacity reduction: Empirical analysis and model predictions

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ABSTRACT

In spite of their widespread use in policy design and evaluation, relatively little evidence has been reported on how well traffic equilibrium models predict real network impacts. Here we present what we believe to be the first paper that *together* analyses the explicit impacts on observed route choice of an actual network intervention *and* compares this with the before-and-after predictions of a network equilibrium model. The analysis is based on the findings of an empirical study of the travel time and route choice impacts of a road capacity reduction. Time-stamped, partial licence plates were recorded across a series of locations, over a period of days both with and without the capacity reduction, and the data were 'matched' between locations using special-purpose statistical methods. Hypothesis tests were used to identify statistically significant changes in travel times and route choice, between the periods of days with and without the capacity reduction. A traffic network equilibrium model was then independently applied to the same scenarios, and its predictions compared with the empirical findings. From a comparison of route choice patterns, a particularly influential *spatial* effect was revealed of the parameter specifying the relative values of distance and travel time assumed in the generalised cost equations. When this parameter was 'fitted' to the data without the capacity reduction, the network model broadly predicted the route choice impacts of the capacity reduction, but with other values it was seen to perform poorly. The paper concludes by discussing the wider practical and research implications of the study's findings.

1. Introduction

It is well known that altering the localised characteristics of a road network, such as a planned change in road capacity, will tend to have both direct and indirect effects. The direct effects are imparted on the road itself, in terms of how it can deal with a given demand flow entering the link, with an impact on travel times to traverse the link at a given demand flow level. The indirect effects arise due to drivers changing their travel decisions, such as choice of route, in response to the altered travel times. There are many practical circumstances in which it is desirable to forecast these direct and indirect impacts in the context of a systematic change in road capacity.

For example, in the case of proposed road widening or junction improvements, there is typically a need to justify economically the required investment in terms of the benefits that will likely accrue. There are also several examples in which it is relevant to examine the impacts of road capacity *reduction*. For example, if one proposes to reallocate road space between alternative modes, such as increased bus and cycle lane provision or a pedestrianisation scheme, then typically a range of alternative designs exist which may differ in their ability to accommodate efficiently the new traffic and routing patterns.

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Through mathematical modelling, the alternative designs may be tested in a simulated environment and the most efficient selected for implementation. Even after a particular design is selected, mathematical models may be used to adjust signal timings to optimise the use of the transport system. Road capacity may also be affected periodically by maintenance to essential services (e.g. water, electricity) or to the road itself, and often this can lead to restricted access over a period of days and weeks. In such cases, planning authorities may use modelling to devise suitable diversionary advice for drivers, and to plan any temporary changes to traffic signals or priorities. Berdica (2002) and Taylor et al. (2006) suggest more of a pro-active approach, proposing that models should be used to test networks for potential vulnerability, before any reduction materialises, identifying links which if reduced in capacity over an extended period[1] would have a substantial impact on system performance.

There are therefore practical requirements for a suitable network model of travel time and route choice impacts of capacity changes. The dominant method that has emerged for this purpose over the last decades is clearly the network equilibrium approach, as proposed by Beckmann et al. (1956) and developed in several directions since. The basis of using this approach is the proposition of what are believed to be 'rational' models of behaviour and other system components (e.g. link performance functions), with site-specific data used to tailor such models to particular case studies. Cross-sectional forecasts of network performance at specific road capacity states may then be made, such that at the time of any 'snapshot' forecast, drivers' route choices are in some kind of individually-optimum state. In this state, drivers cannot improve their route selection by a unilateral change of route, at the snapshot travel time levels.

The accepted practice is to 'validate' such models on a case-by-case basis, by ensuring that the model—when supplied with a particular set of parameters, input network data and input origin–destination demand data—reproduces current measured mean link traffic flows and mean journey times, on a sample of links, to some degree of accuracy (see for example, the practical guidelines in TMIP (1997) and Highways Agency (2002)). This kind of aggregate level, cross-sectional validation to existing conditions persists across a range of network modelling paradigms, ranging from static and dynamic equilibrium (Florian and Nguyen, 1976; Leonard and Tough, 1979; Stephenson and Teply, 1984; Matzoros et al., 1987; Janson et al., 1986; Janson, 1991) to micro-simulation approaches (Laird et al., 1999; Ben-Akiva et al., 2000; Keenan, 2005).

While such an approach is plausible, it leaves many questions unanswered, and we would particularly highlight two:

1. The process of calibration and validation of a network equilibrium model may typically occur in a cycle. That is to say, having initially calibrated a model using the base data sources, if the subsequent validation reveals substantial discrepancies in some part of the network, it is then natural to adjust the model parameters (including perhaps even the OD matrix elements) until the model outputs better reflect the validation data.[2] In this process, then, we allow the adjustment of potentially a large number of network parameters and input data in order to replicate the validation data, yet these data themselves are highly *aggregate*, existing only at the link level. To be clear here, we are talking about a level of coarseness even greater than that in aggregate choice models, since we cannot even infer from link-level data the aggregate shares on alternative routes or OD movements. The question that arises is then: how many different combinations of parameters and input data values might lead to a similar link-level validation, and even if we knew the answer to this question, how might we choose between these alternative combinations? In practice, this issue is typically neglected, meaning that the 'validation' is a rather weak test of the model.
2. Since the data are cross-sectional in time (i.e. the aim is to reproduce current base conditions in equilibrium), then in spite of the large efforts required in data collection, no empirical evidence is routinely collected regarding the model's main purpose, namely its ability to predict *changes* in behaviour and network performance under *changes* to the network/demand. This issue is exacerbated by the aggregation concerns in point 1: the 'ambiguity' in choosing appropriate parameter values to satisfy the aggregate, link-level, base validation strengthens the need to independently verify that, with the selected parameter values, the model responds reliably to changes. Although such problems–of fitting equilibrium models to cross-sectional data–have long been recognised by practitioners and academics (see, e.g., Goodwin, 1998), the approach described above remains the state-of-practice.

Having identified these two problems, how might we go about addressing them? One approach to the first problem would be to return to the underlying formulation of the network model, and instead require a model definition that permits analysis by statistical inference techniques (see for example, Nakayama et al., 2009). In this way, we may potentially exploit more information in the variability of the link-level data, with well-defined notions (such as maximum likelihood) allowing a systematic basis for selection between alternative parameter value combinations.

However, this approach is still using rather limited data and it is natural not just to question the model but also the data that we use to calibrate and validate it. Yet this is not altogether straightforward to resolve. As Mahmassani and Jou (2000) remarked: 'A major difficulty ... is obtaining observations of actual trip-maker behaviour, at the desired level of richness, simultaneously with measurements of prevailing conditions'. For this reason, several authors have turned to simulated gaming environments and/or stated preference techniques to elicit information on drivers' route choice behaviour (e.g.

[1] Clearly, more sporadic and less predictable reductions in capacity may also occur, such as in the case of breakdowns and accidents, and environmental factors such as severe weather, floods or landslides (see for example, Iida, 1999), but the responses to such cases are outside the scope of the present paper.

[2] Some authors have suggested more systematic, bi-level type optimization processes for this fitting process (e.g. Xu et al., 2004), but this has no material effect on the essential points above.